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ADDRESS BY MR. E. W. STERN

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On the occasion of the presentation of portrait of Dean Galbraith to the University.

This honor conferred on me by my fellow graduates and the undergraduates in Applied Science of the University of Toronto is one which is most flattering, and which I most deeply appreciate and can never forget. No greater pleasure could come to me, than to return to my old home and old college after many years, to be with you all and to be asked to participate in such an event as this, the public expression of the appreciation in which our beloved preceptor is held.

There might have been selected one far more worthy of this honor and more able to express eloquently the thoughts which an occasion as memorable as this should bring forth, but none more in sympathy with it, nor more impressed with the sterling worth of the man in whose honor we have met this night.

I do not propose to speak a eulogy of Dean Galbraith, because as we are all one of his family, so to say, it might perhaps not be in good taste, and besides a parent should not be praised too much by his children, it might spoil him, and he might take advantage of us; nor to refer, except briefly, to the evolution of the School of Practical Science into the Faculty of Applied Science of the University of Toronto and its steady growth under his fostering care, with the loyal support of his able colleagues, from its modest beginnings, some thirty years ago, to the great institution it now is, because such a recital would deal practically with the commencement and development of technical education in this province with which his career has been most intimately associated, and there are those much better qualified to speak of this than I; but rather to try and express what we, his old pupils, know of the man, and our appreciation of him and to tell you of those sterling qualities of mind and heart, the modesty, the thoroughness, the patience as a teacher,

the kindliness and the human attractiveness of his personality, the interest in the welfare of his old pupils, all of which has so endeared him to us, and has had such a strong influence upon our lives.

My first acquaintance with him goes back a long, long while ago—twenty-seven years—when most of the young gentlemen now before me had not yet made their appearance. I called at the old brick school-house to ask him about the studies which were taught in the School of Practical Science. My notions about the profession of civil engineering were very vague, and I asked for enlightenment. As a result of our interview, I was so taken by some indefinable quality in his personality, that I decided to enter this school and learn civil engineering.

It was then a very modest school, only three students in the third year, three or four in the second, and about one dozen of us freshmen. The faculty in Engineering consisted of Prof. Chapman, Dr. Ellis, Dr. Pike and Prof. Galbraith, and we had a few hours a week in University College, under Prof. Loudon and Baker. All the Engineering lectures were given by Prof. Galbraith as well as the field instruction in surveying, and for three only too short, happy years, he led us all the way through the mysteries of mechanics, thermodynamics, descriptive geometry, hydraulics, etc.

We were indeed fortunate in those days on account of the small size of the classes in having so much of our preceptor's attention; we could not help but learn under him, and learn to think for ourselves. The class was thoroughly in earnest in its desire for knowledge, for such was the inspiration of his teaching. His patience was untiring and he never hesitated to go over and over again, a subject which we could not understand, until we had it. While he maintained discipline, it was done without harshness, his teaching was thorough without being pedantic. He impressed us with the importance of getting at the bottom of things and of trying different methods. His lectures were informal, his methods not academic. He would put down a difficult problem on the blackboard, and sit down and think it out with us. If the problem were one involving a knowledge on our part, say of certain theorems in calculus or algebra which we were supposed to know but which we were not clear about, he would go back and drill this into us before proceeding with the problem in hand.

I can recall to this day, how persistently he kept at us until he made us understand that in a beam, the neutral axis corresponds with the centre of gravity of the cross section, and that $\frac{M}{I} = \frac{p}{y}$. Rankine (peace to his ashes) was even made plain. He untangled many of his knotty theorems. As I think back, I can still remember away off in the distant past something about the

internal stress, which we underwent to understand the ellipse of stress, adiabatics, isothermals, and to draw the shadow which a cone casts on a parabaloid of revolution. He really did clarify in our minds these mysterious things.

The lectures would be enlightened with flashes of keen humor. I remember that once in expounding the theory that the forces acting on a body are in equilibrium when it is either at rest, or in motion through space at uniform velocity, I asked the question, "What would happen if the body struck me?" The answer came quick with a mischievous twinkle of the eye, "Well, let us see—if it struck your head, it would depend on its quality as to whether it rebounded, or went through."

His technical qualifications and breadth of view were such that we soon realized we were under the guidance of a master mind. It was, however, the human quality of the man, his fineness, his way of thinking and talking straight, his kindliness and interest in each of us and his sympathetic nature, which appealed most to us. He was a man, every inch of him, and one of nature's own noblemen. He never preached at us, nor did he ever talk about what was right or wrong, but somehow or other, remarkable to say, we absorbed ethical teaching from him. I have spoken with many of our graduates, and they all agree with me in this;—we seemed to feel what he thought was the right thing to do.

He was not only popular with us his students, but he was appreciated by all sorts and conditions of men. The Ojibwa Indians call him by a name which means "The Little Chief with the noonday face." I recall personally, a suggestive incident bearing on this phase of him. Twenty-six years ago, during my summer vacation, I was on a surveying party in Nipissing; one night our party were encamped near a Hudson Bay post called Fort McLeod, at the mouth of Sturgeon River. In talking with the factor, whose name I cannot just now recall, he asked me if I knew a little professor from Toronto—John Galbraith by name. I told him that I did know him and that I was then studying under him. He said to me: "He is the finest man I have ever met, he tells the best stories—I would like him to visit here again. You come with me and sleep in a bed to-night," and we drank the professor's health from a black bottle, and thanks to him, I slept in a bed that night, the first in four months.

There were five of us who graduated in the class of 1884, a striking contrast with present times. I shall never forget his farewell address. Calling us together, he told us that now having completed our course at the school, we must start out in the world with the idea in our minds that we knew nothing whatever about engineering, and should commence our practical work at the bottom. It was characteristic of the man's modesty and thoroughness; never was better advice given, for we started

out in the world with no false notions of our importance, and worked our way up gradually without friction.

Those of our younger graduates whom I have met in recent years, as well as the older ones, have nearly all appeared to me as having some certain characteristics in common, namely, thoroughness and modesty. I know of none who have been failures in life.

After leaving the school his personal interest did not cease, for he looked upon his old students as his children. My own correspondence with him has been kept up steadily during the past twenty-five years, and so it has been with many others.

Dr. Galbraith brought to his life's work a rare fitness for it, for besides the personality which I have spoken of, not only were his academic attainments of the highest, but his practical experience in his profession, in railroad work, on surveys, and in the shops was most thorough. His broad experience, therefore, enabled him to separate as it were the wheat from the chaff, in our work, and temper theory with practical experience. He impressed us with the fact that while theory was right as far as it went, we were liable to forget some very important things in our premises, and that therefore we should always scan our conclusions from the perspective of common sense, always seeking for and considering carefully, the results of practical experience.

Had he chosen to follow the practice of his profession rather than teach, he would undoubtedly have been, before this, at the top of his profession in Canada. Only recently, as a member of the Royal Commission on the Quebec Bridge disaster, together with his able colleagues, Messrs. Holgate and Kerry, he labored most indefatigably without cessation for eight long months, and the report submitted by this commission was characterized by the leading technical journals in the United States as being the most able, thorough and valuable that has ever been published, in any language, of a great engineering disaster, the lessons of which, not only from the technical standpoint, but from that of organization, morale and business methods, are so clearly set forth as to make it a most valuable contribution to engineering literature and worthy of the careful study of any engineer, no matter in what special lines he may be working. I may note, too, that in this report, while the facts have been most clearly set forth, the human spirit of charity and sympathy with the unfortunate engineers upon whose shoulders the responsibility for the disaster rests, permeates it.

Of this commission, a colleague, Mr. Kerry, formerly a professor at McGill University, and now a very prominent consulting engineer, who had been closely and intimately associated with Dr. Galbraith for months, told me that he was one of the most likable men he had ever met and asked me if we,

his old pupils, realized how big a man he was. Very quickly I reassured him on this point.

I will digress a minute to quote further what Mr. Kerry has to say about him from an article in Engineering News, published a few months ago, when Dean Galbraith was elected president of the Canadian Society of Civil Engineers. He says:—

"To the development of the School of Practical Science Dr. Galbraith has devoted the whole of his time and abilities, consistently refusing to undertake professional work as a consulting engineer whenever it was likely to interfere with his duties as a teacher. The School of Practical Science is to-day the largest and most rapidly growing engineering school in Canada. This, while in a measure due to the great prosperity of the Province of Ontario, must in large part be credited to the work that has been done by Dr. Galbraith; for the successive classes of graduates have recognized the thoroughness of their training, the simple devotion to duty of their professor, the soundness of his professional knowledge and the manliness of his personal character so fully that it is questionable whether any other engineering school on this continent gets such enthusiastic advertising and such active personal support from its own graduates. It is characteristic of the man, and of his estimate of his own attainments, that he has repeatedly refused permission for the publication of his lectures and has contributed but little to the sometimes too-swollen stream of technical literature. Dr. Galbraith's work since 1878 may be aptly described as that of a fashioner of tools which have been widely used by other men in the construction of the great engineering works of Canada; the standing of the graduates of the School of Practical Science is evidence of the thoroughness of his fashioning."

It is quite evident from this article that Mr. Kerry, like all of us, has been unable to resist hypnotic influences.

As I have already said, there is no question but that Dr. Galbraith would have become a leader in his profession, had he chosen to follow it. In fact, his ethical and technical qualities would have made him a leader in whatever line of work he would have pursued, for his personality is such as to inspire confidence in those who might have availed themselves of his services, and also, would cause those who were under him to work most loyally and efficiently for their chief. But he could not have become greater than he now is. His service to the state and society from his long years of steady, devoted adherence to his life's work has been invaluable. He would have been wealthier without doubt, but he is one of the few who, having placed duty above material things, has set an example for us all.

The growth of the Faculty of Applied Science has been phenomenal. In thirty years it has grown from about 30 in all the classes to 770. This great increase has involved a tremendous amount of work on the part of the faculty and its leader, for

not only was the great increase in numbers of pupils to be taken care of, but these past thirty years have been most prolific in advance in engineering science, and the School under his able leadership has kept fully abreast of the times, so that now it stands second to none in America in thoroughness and efficiency and ranks among the leading technical schools of the world.

The great success of this institution has undoubtedly been due to Dr. Galbraith, but we give full credit also to the very able, efficient and loyal support he has had from his colleagues in the faculty, and to Dr. Ellis in particular I may refer as being one of the old guard whom we remember most pleasantly and gratefully from the old days.

Dr. Galbraith's life furnishes an object lesson to every one of us—the value of thoroughness, modesty, and human sympathy in all the walks of life; and although all cannot be at the top of the ladder, we still can be steadfast and conscientious in our day's work, and above all, be respected wherever our lot in life should happen to fall.

We, his old pupils, are his life-long friends. We owe him a debt which can never be repaid. We wish him many, many more happy years of life and usefulness, and we give him our blessings.

This portrait, the work of Mr. J. W. L. Forster, is the gift of practically all the graduates and undergraduates in the Science Department, and our sincere thanks are due him for the faithful and sympathetic likeness which he has produced.

As marking the anniversary of the thirtieth year of Dean Galbraith's connection with this institution, and as a small token of our appreciation of his services to us, we take great pleasure in presenting to you, sir, for the University of Toronto, this, the portrait of one of its most gifted and worthy sons, and of one of its most beloved preceptors.

ADDRESS—ROBERT MOND*

Gentlemen—Principal.

Your Professor Haultain has requested me to address a few words to you, a request which gives me peculiar pleasure to be able to accede to.

You who have assembled here from all parts of the Dominion in order to acquire the knowledge requisite for the development of the many and varied mineral resources of the northern and greater part of this Continent are squaring your shoulders to take up a burden whose magnitude and whose importance are scarcely to be over-estimated.

All the faculties with which your forbears and surroundings have endowed you will find scope for their widest development. Only by your whole-hearted devotion and attention, accompanied by reverence, both to those who teach you by word and by letter, will enable you to worthily prepare yourself for your life's work.

Those of you who are preparing yourselves for mining will have to acquire a moral and mental probity and rectitude such as is demanded of few of your fellow mortals. On your opinion, though not directly expressed for publication, not only fortunes but the weal or woe of widows and orphans may depend. You will be responsible for the welfare of many individuals of various types and nationalities. You will be held responsible for the safety of irresponsible subordinates. And proceeding to technicalities you will have to recognize the occurrence and size of the ore deposit, determine its position, decide its development, the correct system of drainage, the methods of concentration, of roasting and smelting, possibly of refining, and the arrangements for transportation. This involves a knowledge of geology to determine the stratification and geotectonic structure of the environment, mineralogy to enable you to identify your minerals, chemistry to enable you to assay your ores and understand the theory of your smelting process, the mechanical parts of physics to understand the principles of your concentrating processes; mechanical engineering to keep your plant running; electrical engineering, where electricity is available; civil engineering for your methods of transporting, and architecture, as it applies to the buildings which you will have to erect.

It would not be humanly possible, and no one would expect it of you, to be pastmasters in the formidable list of different branches of knowledge I have thus enumerated; but the more you know of all these branches, and especially the more efficient you are in any one of them the more useful and efficient will you be in your future career.

And here let me warn you. You must not anticipate that the few years you will spend at this University will enable you

*Delivered before Mining Section of the Engineering Society, November 5th, 1908.

to attain to this knowledge. That is not its object. But you will be taught and you will acquire the system and method which will train your mind to assimilate this knowledge from hour to hour and day by day, when you have said farewell to your Alma Mater, and as you advance in years your thoughts will turn in deep and earnest thankfulness to those who have aided you in your own evolution.

You will be called upon to go forth to the uttermost corners of the earth among strange people, and stranger conditions, to examine strange propositions. You will be unaided, unguided and unchecked, surrounded by people whose self-interests may be diametrically opposed to yours or those of your employers.

You will be exposed to personal discomfort, if not danger, to the wiles of the unscrupulous, and to the facile lie of ignorance. You will have to read human characters and learn to use your enemies as well as your friends. You will be liable to maligning, overt or dissimilated attempts at corruption; hence I say to you that you require a code of honor, a standard of morality higher than is generally demanded of mankind.

In the management of men there is only one rule which is universally accepted, and that is an absolute fairness and justice, well designated as square dealing, with those one employs. All favoritism is as disastrous to an employer of labor as it ever was to the proudest monarch history records.

A thorough knowledge of geological principles will prevent you from searching for one where it could not possibly occur, it will give you valuable information in regard to folds and faults, but it will never tell you whether the ore is payable.

The use of mineralogy in enabling you to properly classify your ores is self-evident, but chemistry is your most important helpmate.

It tells you whether your ore or your rock goes on the dump, whether your stopes are worth working, whether your tailings are not richer than your ore, whether your water corrodes your pumps and boilers and whether your coal is not heating air instead of water. And in smelting and refining you are dealing with purely chemical reactions. There chemistry will tell you whether your cyanide runs down the drains or your metals away with the slags, whether your water is fit to drink or your air fit to breathe; and chemistry not only warns you, but also tells you how to rectify any error thus made.

In concentration plants, either dry centrifugal magnetic or wet, with or without oil, the physical properties of matter are of the greatest importance. Your processes depend on graduation both of volume and weight and you will find by careful and conscientious experiments, that concentrating plants and concentrating plant manufacturers' catalogues are not synonymous.

One of your most important and conscientious tasks will

be that of sampling. Here again it is only by fully understanding the underlying principles that you will be able to adapt methods to your materials which will give you concordant results.

You will have to be expert surveyors and neat and quick draughtsmen or your experience may tally with that of the Roman engineer who, in the second century A.D., having to drive a tunnel for the conveyance of water through a mountain in the ancient province of Mauretania (the present Morocco) surveyed the mountain and started to work from each end. After some time the contractor was sent for by the Governor of the Province, as the work showed no sign of completion, and it was found that each party of miners deviating slightly to the side had nearly driven two tunnels through the mountain.

Of mechanical, electrical and civil engineering you will acquire the rudiments and you will have many opportunities of perfecting your knowledge by subsequent experience. Mining engineering proper you can only learn in a mine. But your own personal experience will of necessity be limited to special cases, and you must seek every opportunity, both by reading and seeing, to acquire as extended a knowledge as possible.

The correct type and use of rock drills, the most advantageous methods of blasting, the correct methods of supporting the roof of the mine, the timbering of shafts and of levels, the methods and means of extracting the ore, the determining of the boundaries, all so varied in application, are still reducible to a few leading principles which you will have to acquire.

And as regards exploration, the first necessity for this is an adequate knowledge of similar ore deposits situated in the vicinity, or in other parts of the world, which from analogy enable you to understand their general mode of occurrence, their recognized methods of extraction and their probable origin. We are not endowed with a sense which enables us to see through a piece of rock, and the mechanical means which have so far been elaborated—magnetic surveys, diamond and other drilling, stripping cross-cut pits and shafts are both expensive and laborious methods of acquiring uncertain information. You must consequently be well acquainted with the use and abuse of these methods so that you can employ them as useful tools for aiding your judgment and keep continually aware of their strict limitations.

In whatever branch you may be occupied one thing above all others will be required of you, and that is, that you embody your observations or findings in a clear, logical and concise report. To few is given the gift to do so, therefore the greater the necessity of acquiring the habit of study. It is of equal advantage to the writer and to the recipient, as it compels the former to recapitulate and arrange in his mind the data for which he is responsible, whilst for his superior or employer the reports are the best means for gauging his capacity and char-

acter irrespective of the value of the report as regards the matter in hand.

A knowledge of book-keeping and store and stock-keeping should be acquired. The methods are simple, and proper organization immensely facilitates one's work and prevents waste and worry.

And, finally, if you have discovered and developed a mine, extracted, concentrated under economical conditions a valuable ore, this is only the first step in making the metal therein contained available for human use. It now has to undergo a refining process and be converted into a shape such as is required by the market.

This involves an entirely new state of affairs. Up to this stage all the necessary operations have had perforce to be carried on in close proximity to the mines so as to reduce to a minimum the transport of waste material.

In the refinery the ore is only one of several raw materials. It is usually the most valuable, and hence best able to stand heavy transportation charges. Others, such as fuel, fluxes. power, acids and other chemicals are more bulky and mostly less valuable than the ore. Proximity to the readiest means of transportation giving access to the world's markets for the finished products and bye-products will be the determining factor of its location.

Refineries are also associated with a large number of cognate industries who draw upon the refinery for their raw ma terial. Their proximity not only reducing cost of transporting, but also enabling the consumer to speedily obtain rectification of errors and attention to his individual requirements an element of the utmost importance in the rational and logical development of an industry.

Those of you who will hereafter be associated in the manufacture of the numerous alloys of iron, will learn the part the composition of your ore will play in the subsequent usefulness of the pig iron produced. How phosphorus silicon, manganese, chronium, tungsten, titanium nickel and vanadium, not forgetting carbon will essentially alter its character. Even the student of history and political economy will be surprised at the overwhelming importance the use of metals has played both in the ancient and the most recent times, even as the neolithic stone age was conquered by copper, this by bronze, and that by iron and steel. We find that in the 17th century the adoption of coal by the iron industry abolished the iron industry of the South of England, and drove it into the coal fields. Mr. Gilchrist Thomas' invention of the basic, instead of the acid lining of the open hearth furnace enabled Germany to build up its immense iron industry on the phosphate iron ores of the Rhenish Province, Westphalia and Luxemburg. The celebrated Saracenic Damascus blades of the time of the Cru-

saders owned their excellence to an admixture of nickel which now again is used in our most powerful engines of war.

The search for ores and refining of metals provided one of the earliest means of human interchange. We learn that Egyptian Kings of the 3rd Dynasty about 4,000 B.C. secured copper ores in the Sinai peninsula. We have plans and workings of the time of Seti of the XIX Dynasty about 1300 B.C., Crete and Cyprus grew rich on copper, Athens on the lead silver mines of Laurin. The Etruscans based their industry on their copper and tin mines, the Phoenicians sought gold in Africa and tin in Cornwall. The Romans worked tin, gold, silver, lead and copper mines over the whole of their Empire up to its confines in Northumberland and Spain, and in turn the Spaniards overthrew the Empire of the Inca's and Aztec's in their search for gold on the South American Continent. German miners brought over by Queen Elizabeth revived the mining industry of England, and thence the mines of the most distant parts of the world, from the Yukon to Tasmania, have had to yield their share of the world's riches.

And through these ages the advance of metallurgy can be traced through the successive recognition of the elements of which middle ages are composed. From the middle ages onward before which only the four elements of Aristoteles were admitted each succeeding generation succeeded in isolating, and hence learning to separate from additional metal or element, and this process is so far from being exhausted that my friends, Lord Rayleigh and Sir William Ramsay, only recently succeeded in finding in ordinary air a new constituent gas, organ which constitutes nearly one-hundredth part of its volume, whilst subsequently Sir William Ramsay has succeeded in finding some three more. Uranium has yielded radium to Madame Curie, Bismuth polonium and thorium actinium, whilst my friend, Sir William Crookes, has still quite a number of undefined rare earths of the Didymia-Yttria type awaiting complete isolation.

Complete analysis of the metal-bearing constituents of the Igneous rocks have taught us of the wide dispersion of the elements in the earth's crust, whilst the recent application of such rare elements as Thorium and Cerium to the incandescent gas mantel, as discovered by Dr. Auer, from Welsbach, plainly teaches the impossibility of predicting the useful application of an obstruse scientific discovery, which is equally borne out by the recent industrial application of Osmium and Tantalum to electric lighting.

These recent discoveries should be auguries of great hope to all of you, demonstrating the great harvest that awaits a reaper and which can only be garnered by undeviating devotion and application to the subject of one's study. No reaction is so obstruse and no object so insignificant that a diligent study will not yield a rich reward to the searcher. The collection and

classification of a few petrefactions and fossils has enabled us to actually determine the relative successions of the layers of the earth's crust, and just as finding a few fossils characteristic of the strata underlying the coal will convince us of the futility of further search for coal similarly the determination of the beds overlying it will give you the desired indication.

The way which has to be traversed from the experimental determination in a scientific laboratory to the practical application on a large scale under technical conditions is a long one and fraught with many difficulties. The peculiar aptitude of mind which is best adapted for solving scientific problems in the laboratory is only very rarely accompanied by the power of expansion and assimilation required by the new set of factors involved by operations on a technical scale. Hence no new process fresh from the laboratory can hope for success unless those who take it in hand have both knowledge and perseverance which will enable them to laboriously and systematically grapple with the difficulties as they arise, and use their accumulated experience to the solution of the problem. It has often been said that we only learn by failure. Unfortunately in technical processes no records of the failures are extant from which we might learn what to avoid. Hence we see many promising processes involve the ruin of their inventor, whilst in subsequent years the same process may become one of world-wide adaptation, and if we search for the cause we frequently find that another invention of an entirely different nature has bridged a gap or made some operation economically possible. I might give you as an example the improved treatment of the extraction of gold from the ores, first by the introduction of the cyanide process; secondly, by the application of this process to still poor and formerly unremunerative ores by the adoption of a new and more economic crushing apparatus, namely, the tube mill instead of the battery stamp. Neither of these have any reference to the cyanide process, yet a more efficient crusher has materially increased our resources. I could cite you many similar examples, and also the converse, where some new invention has facilitated a large number of known processes such as application of electricity as a motor power to scattered units, or to the application of steel specially prepared for armour piercing shells to the jaws of the stone crusher, or the application of ice-making machinery to shaft sinking and quicksand.

In this connection I may be permitted to refer to my father's discovery of the extraction of nickel from its ores by the nickel carbonyl process.

My father, Dr. Ludwig Mond, had devised a method for obtaining hydrochloric acid directly from the ammonium chloride, which is a by-product of the ammonia soda process.* The method consisted in passing the vapour of NH_4Cl over magnesia, and the apparatus was fitted with nickel valves, because

this metal is not acted upon by the vapour of NH_4Cl. On the laboratory scale these valves worked perfectly, but on the manufacturing scale they became covered by a black crust of carbon and became leaky. This was traced to the presence of a trifling quantity CO in the large scale plant and this led to the investigation of the action of nickel on carbon mononide. This finely divided nickel reduced by hydrogen at a temperature of 400°*C* was treated with CO in a glass tube at varying temperatures for a number of days, and was then cooled down in a current of CO. To get rid of the poisonous CO the gas was lit as it escaped from the apparatus. When the apparatus was cooling down the gas became luminous, and increased in luminosity as the temperature fell below 100°*C*. On a cold plate of porcelain put into this luminous metallic spots were deposited similar to the spots of arsenic in Marsh's test. On treating the tube through which the gas was passing a metallic mirror was obtained and the luminosity disappeared. These mirrors were found to consist of pure nickel. The best results were obtained by treating nickel with CO at 50°*C*, and by passing the gas so obtained through a tube cooled with snow and salt liquid nickel carbonyl was obtained, freezing at —25°*C*, boiling at 43°*C* and decomposing at 150° into its components, CO being set free and nickel being deposited as a dense metallic film on the side of the vessel in which it is heated. A large plant was erected near Birmingham to utilize these discoveries for the production of nickel from Canadian nickel copper matte from Sudbury.

The matte which contains 40% nickel and an equal quantity of copper is carefully roasted to drive off sulphur, and is then subjected to the action of water gas or producer gas rich in hydrogen in an apparatus called a "reducer", at a temperature never exceeding 400°*C*. From this apparatus the substance now reduced to the metallic state is carried to the "volatilizer", in which it is subjected at a temperature not exceeding 80°*C* to the action of CO gas.

The CO gas charged with nickel carbonyl leaving the volatilizer is passed through tubes or chambers heated to 180°*C*, in which the nickel is deposited and the CO is used over again.

But the main lesson brought out by these considerations is the interrelation of all branches of human knowledge and endeavor. We all and each one of us are conscientiously or unconscientiously increasing the scope of human knowledge, and the more facile we are in the task allotted to us, and in seeking for the truths with a single "I", the further shall we proceed in the direction of increasing the productivity of the individual, assuring him of a greater share in the world's goods and of leisure to partake of them, while his work shall become his most enjoyable occupation.

Journal Society Chemical Industry, Nov. 30th, 1895.

A PLEA FOR THE BUSINESS TRAINING OF THE ENGINEER

R. A. ROSS, E.E., (Toronto).

The only justification in the eyes of the community for the existence of the engineer are the results which he obtains. His business is a purely utilitarian one, the object being the production of value. Value is not measured by the cost of an engineering construction, but by the results obtained therefrom when used as a tool for the extraction of dividends. The value of the engineer to the community being determined by the results obtained from his engineering, it becomes pertinent to inquire when such results are shown. These become apparent only when the work for which he was responsible has been in operation for a time and operating profits or losses can be determined.

Without drawing the lines too closely there may be conceived to be three stages in the life of an enterprise:

1. The scientific—when the tool is forged by the engineer.
2. The business—when methods of using the tool are evolved and used.
3. The economic—when the results of the tool and its handling become apparent.

The engineer as a purely technical man will consider his work done at the end of the first stage, leaving to other hands the completion of the task and the obtaining of results therefrom. This tendency is fathered by the purely technical nature of the training which he has received, fostered by a lack of business knowledge in which he finds himself deficient and ingrained in his system by the attitude of the business world towards him, which believes the engineer to be lacking in business ability whereas it is only lack of training and confidence.

The general result so far as the engineer is concerned is that by keeping his nose so closely to the technical grindstone he has little opportunity, or even desire, to look up and see what the larger business world is doing with his product; he therefore does not take his real position in the scheme of things and attract that attention to himself and his profession which he should, nor does he do that full justice to the community which has educated him, and which has a right to demand the highest dividend possible on capital invested in his training.

No remark is more frequently heard, especially among financial and business men, than that the engineer does not understand business. And this is in general true. He is therefore hired by a company, and regarded by it merely as a species of glorified plumber. He constructs the tool with which the

*Mr. Ross is of the firm of Ross and Holgate, Consulting Engineers, Montreal, and has recently been engaged to deliver a course of lectures on the Business of Engineering, at McGill University.

financial man works and without which he could have no standing in the community, and being given this tool he is able to bring business methods to bear and produce results, for which he and not the engineer is given credit and reward.

The engineer is a man with a trained mind, trained to logical reasoning and deduction, brought up on good, old Euclid, thoroughly grounded in rigid scientific principles and taught to think straight. If, therefore, he applies his logically trained mind to business and economic matters with one-half the diligence which he exercises in his purely engineering functions, it is difficult to see why he should not obtain better results than the business man who generally has had no real training in business, but has absorbed such knowledge as he possesses from the business atmosphere surrounding him—does not read, study, or examine into the real reasons of things, and knows only business usage and custom. If this be doubted, inquire from business friends as to the amount of reading and real study they have given to business matters, it will be found to be inconsiderable. As a matter of fact, the engineer side-steps a business proposition whenever he can, stating in effect, if not in words, that his business is engineering and leaves the business of what should be his work to others, when given a certain amount of study and courage he could settle these questions satisfactory for himself and to the benefit of the public. The reason for this attitude on his part toward the field which promises him an improved status as a citizen, a broader knowledge of the world at large, and increased dividends, is to be found in the fact that the business part of his training is not taken up or even hinted at during his college course.

It is, of course, impossible that an art such as business is can be taught in a college devoted to science, but neither can the art of engineering be taught there. Whether there is a science of business is very questionable. There is certainly nothing in the nature of an exact science, nor even of an approximate science, but there are certain laws and general principles which if absorbed by the student during his college course would give him a different outlook and broaden his horizon. He would at least learn that there is nothing weird and incomprehensible in ordinary business terms or business methods and therefore be encouraged to extend his field of operation beyond the technical so as to embrace the business and economic end of the subject.

If, however, through lack of ability or aptitude in business matters, or through the bent of his mind being purely scientific, he does not find an opportunity to expand in the direction indicated, yet he will at least be able to understand the terms used, and to talk intelligently to men in the business world.

This expansion of the Engineer's sphere of usefulness is evidenced in the career of certain engineers in other countries

who, beginning as purely technical men, have since launched out into contracting, and finally added financing and operating, so that they in their business have forged the tools, have used them and have obtained results, and the credit and returns are all theirs.

The rapid expansion of industrialism is making its demands for trained men felt more and more, and engineers are being chosen for administrative offices in large corporations and as the directing forces in large enterprises, and this tendency must of necessity increase, and who are better fitted to operate under directions of the laws of men and with a knowledge thereof than those who have built well under the much more rigid and exacting laws of nature.

In any system of engineering training, science must of necessity be the foundation, but upon this foundation the engineer may erect a superstructure which will be visible to the public, and attract attention to the fact that he is a power in the community. This superstructure, which may readily be a part of engineering, is dedicated to the business and financial departments of his business; without the foundation the structure is useless, but the foundation itself not being visible receives precious little attention from the community when the building is complete. The basement rentals are also low.

The institutions wherein engineers are taught must in justice to the profession keep pace with this tendency, and that they are beginning to do so is evidenced by the fact that a number of colleges in other countries have added to their purely technical studies a course on the business and economic aspects of engineering. In this country, McGill is about to set the example, and it would appear that the other technical schools will have to follow suit or their graduates will be distanced in the race for preferment.

There are two arguments against adding a course of this kind to the curriculum of a science school—

1. That the students are already overburdened with work.

2. The reluctance of the authorities to teach anything but science.

As regards the first, it seems to be a question as to whether certain of the more purely scientific studies could not if necessary be dropped in favor of the more practical course here-advocated, but it is thought that this may not be necessary as a fairly extensive course can be given, covering only the principles of business, without overburdening the student, for the reason that his training having been along rather strenuous lines, demanding a high degree of concentration, the study of the mechanism of business will be found to be child's play by comparison.

The second objection can be met by asking whether the college is not for the inculcation of principles. If this is true as

regards science, why not as regards the business of engineering.

The engineer as he develops and gets away from purely technical routine work is supposed to be able to draw up specifications, make contracts, hire and direct labor, and report on properties. These are within his legitimate field as at present understood, and yet all of these demand that he should have in reason a knowledge of money and values, of business methods and some knowledge of law, and that he should be able to present his reports in such a way as to be readily understood by business interests.

The mere expansion of these functions with the same knowledge of principles brings him to a point where he should be able to present a financial scheme for the consideration of financial people, and practically to act as their engineer, promoter and director of the scheme at its inception and thereafter. He should be able to operate it to a successful issue, to obtain commercial results and dividends. To this end, in addition to the knowledge of business which the engineer should have to enable him to draw up specifications, contracts, etc., he should have a knowledge of the general business methods of the community in which he lives. He should understand something of stocks, bonds, bills of exchange, notes, the formation of companies, of partnerships, the general laws relating thereto, the functions and powers of different corporation officials, and the method of incorporating companies. These are matters, the principles of which an engineer trained to study can acquire. To practice is of course a different matter, and results will depend upon his ability in dealing with the world as a business proposition.

His scientific training has taught him to deal with the laws of nature. His business training should teach him how to deal with men and money and the laws relating thereto. Business has not been taught or developed as a science, and it is therefore considered an art, and ability therein can only be developed by practice. But this is so even in engineering, the science of which is taught in the colleges and the art developed later in the larger world of practice.

It is not expected, nor is it desirable that the engineer should by thus expanding his functions, eliminate the lawyer or financier. But his knowledge of business should on the other hand indicate the necessity for these gentlemen's services, and above all show just when and where their services are needed and enable him to appreciate them at their proper value when given.

In short a business training should develop a new view of his relations to other professional men and place him in the position of engaging their services rather than acting as their servant.

The engineer is a utilitarian to a commanding degree and

much more so than the other professional men, such as the doctor, lawyer and clergyman. The lawyer is a special pleader and does the best he can with the case given him. The doctor buries his mistakes. The clergyman deals in the future, but the engineer has to deliver the goods and the goods have to be commercial, therefore why restrict an engineer's education to purely scientific subjects, and why not expand his horizon to enable him to take the position in the community which he deserves and can command, and enable him to reap the rewards both in credit and dividends for which such training fits him.

NOTES ON BRICK AND BRICK PIERS.

P. GILLESPIE, B. A.Sc.

A close approximation to uniformity in physical properties is not usually revealed by a series of tests on bricks in which raw material and method of manufacture are known to be substantially the same. Bricks taken from the same locality in a kiln will show results in testing which differ by considerable magnitudes. If different experimenters have operated, the results will differ much more widely. With steels and irons on the other hand, much greater uniformity is found where circumctances lead us to believe uniformity exists. Results obtained from tests on samples of these materials in cases where the process is known to be constant, differ by probably ten per cent. at the outside. What is the explanation of the difference?

In the first place, this phenomenon is due to lack of uniformity in the clay product; in the second place, to the fact that the methods of conducting tests on bricks have not been standardized to the same extent as tests on steels and irons have been. An illustration will make this clear. In conducting the crushing test, some operators employ steel plates. Some crush between cushions of blotting paper while others imbed in a batter of neat cement or of plaster of Paris. Manifestly, even if the material *were* of uniform quality, comparable results would under such diverse methods of manipulation, be very difficult of attainment. To illustrate the effect of such non-uniformity of method, a series of tests reported in Tests of Metals, 1901, is valuable. Crushing tests were made on nineteen varieties of brick, each variety being tested in three different ways, viz.—with a plaster of Paris bedding, between cardboard cushions, and between pine boards. The first method in most cases gave the greatest strength and the last the least. Of course there are exceptions, but in a range covering nineteen varieties, the general conclusion will be significant.

RESUMÉ OF RESULTS.

	Mean Strength pds. per sq. in.	Relative Strength.
Tests of Whole Bricks—		
Plaster Bedding	9,060	100
Cardboard Cushions	7,380	81
Pine Cushions	5,480	60
Tests of Half Bricks—		
Plaster Bedding	5,640	100
Cardboard Cushions	4,430	79
Pine Cushions	4,540	81

Suppose, now, these details of method and other local settings are unknown. Suppose that different experimenters have obtained these results by different methods and, as is often the case, have neglected to state the *modus operandi.* How much accuracy in such an instance would the ordinary layman's opinion contain?

The reports of the Watertown arsenal, extending over a period of many years, contain a vast amount of experimental data on bricks and brick piers as well as on other materials. Conclusions, however, are rarely drawn and deductions from experiments seldom appear in these volumes. The reader is left to make his own generalizations, which task where data are insufficient is sometimes a difficult one indeed. At the outset then, one must be careful as to what conclusions can in fairness be drawn. If the data concerning the tests be meagre; if the results have been obtained by different operators; if the methods and materials have not been identical, and finally if the number of experiments be not large, generalizations must be made with the utmost caution. The purpose of this short article is to examine the records of tests on brick and brick masonry with a view to showing some of the peculiarities and limitations of the latter and the precautions which in manufacture or construction contribute to its strength.

In order first of all to get a conception of the position occupied by brick among the various materials employed in masonry construction, crushing strength alone considered, the following table has been compiled. The data have been selected from the records of experiments conducted in the Engineering Laboratory here on Canadian building materials at various times during the past ten or twelve years. As the method of conducting the tests has been uniform throughout, it is believed that the values given are indicative of the strength of the materials tested and enable us to place them in something approaching their true relative positions.

Concrete Blocks	400 to 1,500 lbs. per square inch		
Sand Lime Brick	1,250 to 3,600	"	"
Soft Burned Clay Brick	1,000 to 2,000	"	"
Hard Burned Clay Brick	2,000 to 5,700	"	"
Pressed Brick	3,500 to 5,400	"	"
Vitrified Paving Brick	6,000 to 13,000	"	"
Roman Stone (Artificial)	1,500 to 5,000	"	"
Credit Brown Sand Stone	10,000 to 15,000	"	"
Granite, New Brunswick	15,000 to 16,000	"	"
Longford Limestone	19,400 to 22,300	"	"

POROSITY AND STRENGTH.

In the Report of Tests of Material collected at the Louisiana Purchase Exposition, St. Louis, Mo., 1904, may be found the record of upwards of 400 compression tests conducted on many different varieties of brick representing all sections of the United States. On some 113 of these, absorption tests were also made, and these too are reported. The times of immersion averaged 15 days. A study of the relation between porosity and crushing strength is interesting. That the absorption test has a value in determining the hardness or degree of burning for different deliveries of the same kind of brick is generally conceded. That it is of very much less value in comparing bricks from different localities and by different manufacturers is also pretty generally acknowledged. To some extent, the absorption is a criterion of the crushing strength. The 113 absorption tests furnished the data for a plot, the ordinates being crushing strength and the abscissae the percentage absorption. A study of this plot reveals a kind of hyperbolic relation connecting the two variables. Where the absorption is high, the strength is likely to be low. Whether it is permissible to reduce to a formula, a law with which 50% of the determinations disagree to the extent of 20% or less in either direction, may well be doubted. There is, however, a *tendency* of which this is a rough expression—

$$p\,a = 65{,}000$$

where p is crushing strength in pds. per sq. in. and a is percentage absorption.

It should be observed, too, that as different methods of conducting both the compression and absorption tests will modify results, it will be scarcely fair to apply this rule where the method of conducting either test is radically different from that adopted in the tests referred to. The following illustrations are taken at random from the Report:—

BRICK	Absorption	Strength Lbs. per sq. in.
Dark buff	6.2%	8,620
Common red	13.9	4,700
Light red, face	20.4	3,050
Dark red, paver	3.5	11,990
Light gray, sand lime	13.2	5,280

The extent of the disagreement with the formula in two selected cases is shown in the following:—

BRICK	Absorption	Strength Lbs. per sq. in.
Red, Laclede paver	1.0%	4,850
Dark red, vitrified	13.7	13,560

WEIGHT AND STRENGTH.

From the following table representing but eight tests conducted on dry-pressed and mud brick, it appears as though there is also sometimes, a relation between weight and strength.

BRICK	Weight per cubic foot	Crushing Strength lbs. per sqare in.
Dry Pressed	128.3	10,300
do	127.2	8,740
do	124.3	5.940
do	119.8	3,480
Mud	144.3	19,170
do	136.4	15,670
do	130.6	10,420
do	125.4	10,870

In this series, the strength is apparently nearly proportional to the excess of weight over 114 pds. per cu. ft. The relation

$$p = \frac{2000}{3}(W - 114)$$

where p is the crushing strength and W is the weight in pds. per cubic foot will be found to give values fairly close to those given in the table. It is not for a moment supposed that this relation has an extensive application. It is just possible though that for bricks from the same locality and of the same process of manufacture, some such relation might be found to exist. The numerical constants would doubtless vary quite widely in different cases, and their determination would entail the examination of many individual cases.

Mr. James Howard in the Proceedings of the American Society for Testing Materials, 1907, reports a test conducted on a vitrified shale brick manufactured by the St. Louis Vitrified and Fire Brick Company, whose crushing strength reached the phenomenal figure, 38,446 pds. per sq. in. This is the highest crushing value that has come under our notice and indicates the great possibilities for strength possessed by clay products. Howard reports also a crushing test on a brick pier of 5,608 pds. per sq. in., probably one of the greatest on record. He believes too, that the maximum of strength has not yet been reached and looks for higher results from the use of some of the stronger brick which are now on the market. That such may be possible

is evidenced from the fact that the greatest strength in piers, as will be subsequently seen, has been obtained from a combination of the strongest cement jointing and the strongest brick.

MORTAR JOINTING A VARIABLE.

The superiority of cement mortar over lime mortar is well illustrated in the following series of tests reported by the Watertown Arsenal for 1904. In the tabulated results it will be observed that in the case of each kind of brick, supposedly the same in structure and manufacture, three kinds of jointing were employed, viz.: Neat Portland cement, a cement-sand mortar, and a lime-sand mortar. The piers were substantially alike in height and method of construction. From other data published in the same volume, the average crushing values of the bricks (plaster of Paris bedding) have been obtained and are included in the table. The relative strength of pier and brick in each case has been computed also. The piers were 12″ × 12″ × 8′ high.

Pier.	Jointing.	Age.	Strength of Pier, yards per square inch.	Strength of Brick, yards per square inch.	Strength of Pier in Terms of Strength of Brick.
Face, dry-pressed	Neat Cement	1 mo.	2,880	9,490	.30
do	1 C : 3 S	6 mo.	2,400	"	.25
do	1 L : 3 S	6 mo.	1,517	"	.16
Face, repressed	Neat Cement	6 mo.	1,925	6,780	.28
do	1 C : 3 S	6 mo.	1,670	"	.24
do	1 L : 3 S	6 mo.	1,260	"	.18
Face, wire cut...	Neat Cement	6 mo.	4,021	13,720	.29
do	1 C : 2 S	1 mo.	2,410	"	.18
do	1 L : 3 S	6 mo.	1,420	"	.10
Hard, W. Cambridge...	Neat Cement	1 mo.	4,700	10,490	.45
do	1 C : 3 S	1 mo.	1,800	"	.17
do	1 L : 3 S	6 mo.	994	"	.09
Light Hard W. Cambridge...	Neat Cement	1 mo.	1,510	7,090	.21
do	1 C : 3 S	6 mo.	1,519	"	.21
do	1 L : 3 S	6 mo.	732	"	.10
do	1 L : 3 S	5 mo.	809	"	.11
Hard, East Brookfield..	Neat Cement	6 mo.	1,969	4,840	.40
do	1 C : 3 S	6 mo.	1,800	"	.37
do	1 L : 3 S	6 mo.	733	"	.15
do	1 L : 3 S	5 mo.	866	"	.18
Light Hard, East Brookfield..	Neat Cement	6 mo.	1,061	4,470	.24
do	1 C : 3 S	6 mo.	1,224	"	.27
do	1 L : 3 S	1 mo.	465	"	.10
Hard, Mechanicsville...	Neat Cement	6 mo.	1,400	5,810	.24
do	1 C : 3 S	6 mo.	1,411	"	.24
do	1 L : 3 S	6 mo.	718	"	.12

From the above, we obtain the following averages:—

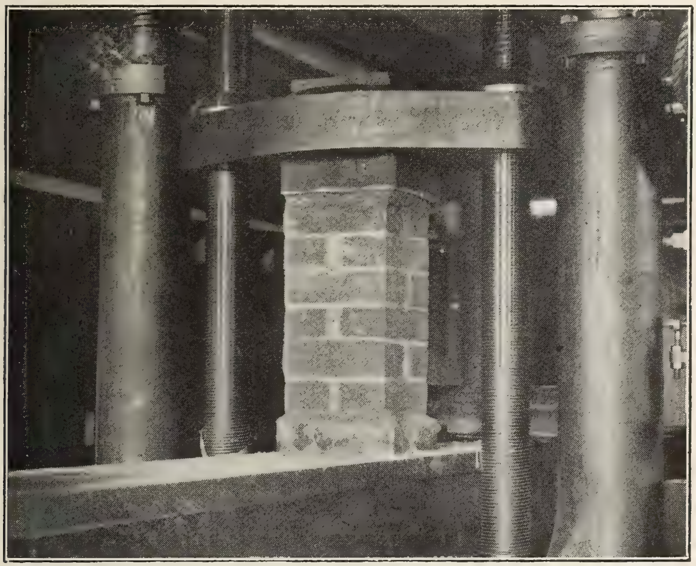
Strength of Pier in Terms of Strength of Brick.

When laid in neat cement, 30%.
" " cement mortar, 25%.
" " lime mortar, 13%.

These may be expressed in terms of the weakest as follows:

Pier having lime mortar, 100.
" " cement mortar, 192.
" " neat cement, 231.

The slight lack of uniformity as to age is not specially significant. A uniform age of six months would doubtless have made these average perecntages somewhat more divergent. It will be observed that weak bricks with a strong jointing or



Brick Pier—Before Crushing

strong bricks with a weak jointing give strengths in piers less than when bricks and mortar are of the strongest possible kind.

A comparison of costs for piers similarly laid is interesting. Brick work laid with 3/8" to 1/2" joints requires 1-3 cu. yd. of mortar per cu. yd. of masonry. If we assume lime at 30c per hundred pounds, sand at 50c per cubic yard, cement at $1.50 per barrel, and labor at current rates, we will find the prices of mortar to be substantially as follows:—

Lime one, sand three, $1.75 per cu. yd.
Cement one, sand three, $3.93 per cu. yd.
Neat cement..........$11.60 per cu. yd.

If the cost of the lime-sand brickwork be assumed to be \$8.50 per cu. yd., that of cement-sand brickwork will be \$9.23, and of neat cement brickwork, \$11.78 per cubic yard. The relative costs will be:

Brickwork laid in lime mortar, 100.
" " cement mortar, 109.
" " neat cement, 139.

From this, it would appear that for the prices assumed, an increase in cost of 9 per cent. through the use of Portland cement will give an increased strength of 92 per cent, and that from an increased outlay of 39 per cent. the strength is augmented to the extent of 131 per cent. These are ample returns indeed and if strength be a desideratum, the use of Portland cement in the

Brick Pier—After Crushing

mortar jointing is an economical method by which to secure it. Outside of experimental laboratories neat cement mortar is almost never used. Moreover, mortars high in cement do not trowel as nicely as those containing lime. In cases where working stresses are low, and where water is not likely to be encountered, the lime mortar jointing for brick masonry will commend itself because of its cheapness.

AGE A VARIABLE.

An examination of the results of tests with a view to discovering the effect of age on the strength of piers supposed to be of the same material and method of manufacture, shows that in most cases the strength increases with age. The exceptions

to the general rule can usually be attributed to differences in material or structure that were not at first known to exist. The unwisdom of making general inferences from few examples must be guarded against. Indeed it is sometimes observed that differences in strength in a series of tests, where there is no intentional variable, is about as marked as where the age varies greatly. From Tests of Metals, 1907, the following are taken :—

Piers of Johnsonburg Pavers laid in neat cement.

Test No.	Age	Strength	Relative Strength
1760	4 days	4,218 lbs. per sq. in.	100
61	7 "	5,608 " "	133
67	1 month	4,281 " "	101
68	1 "	5,003 " "	118

Piers of Shawmut Pavers laid in neat cement.

Test No.	Age	Strength	Relative Strength
1762	4 hours	2,106 lbs. per sq. in.	100
63	2 days	3,733 " "	177
64	7 "	4,514 " "	215
80	4 months	4,089 " "	195

Piers of Wire cut Red Brick.

Test No.	Age	Mortar	Strength	Relative Strength
1820	5 months	1C : 1S	2,300 lbs. per sq in.	100
1816	24 "	1C : 2S	3,662 " "	142

In this last instance, the added strength is due doubtless to the stronger mortar as well as to the increased age. There seems to be little doubt that age will contribute strength to brick masonry. That mortar increases in strength with age is well authenticated by numerous experiments and general observation, and since the strength of brick masonry is dependent partly on the character of the jointing, this inference is quite logical. It is probable that the variation would be more marked with lime than with cement mortar.

WORKING STRESS ON BRICK MASONRY.

From the cases previously cited, the average crushing strength of matured brick piers laid in 1-3 lime mortar is about 80 tons per sq. ft., and for 1-3 cement mortar, 140 tons. A safety factor of 10 will give working stresses of 8 and 14 tons per sq. ft. respectively and these, having regard to indeterminate irregularities in both workmanship and material, do not seem too

large. In many cases, the direct compressive stress on brick masonry due to its own weight only, is but a small fraction of its ultimate crushing strength. A brick wall of uniform thickness weighing 125 lbs. per cubic foot would need to have a height something in excess of 1200 feet in order to exert by its weight alone, a crushing stress of 80 tons per sq. ft. at the base. In buildings where roof and floor loads are carried to walls or piers and supported thereby, high compressive stresses may be developed in the masonry. Wind action, on walls and chimneys for example, produces additional compressive stresses on the leeward side and possibly tensile stresses on the windward. Baker cites a case of a brick chimney in Glasgow, Scotland, 468 ft. high at the bottom of which the stress due to dead load alone is 9 tons per sq. ft. It is estimated that in heavy gales this is increased on the leeward side to 15 tons per sq. foot. Roof and arch thrusts operate outward and earth pressures inward in certain cases, both giving rise to secondary stresses. These considerations will serve to show that stresses exceeding those due to direct loading only, have frequently to be provided for, and where these additional stresses cannot be computed, a wider margin of safety must be allowed. A reference to the building codes of several representative American cities shows the following to be the maximum permissible stresses for brick masonry. The stresses are given in tons per sq. ft.:

	Boston	Buffalo	New York	Chicago	St. Louis	Philadelphia	Denver	Toronto	Montreal
Hard Burned Brick Laid in									
Portland Cement Mortar			15	12½	15			12	15
Cement Mortar and Lime	12		11½		11½	12		9	12
Lime Mortar	8	6	8	6½	11	8	8	6	8

HEIGHT A VARIABLE.

In column formulae generally, we observe on the part of the designer, a recognition of the principle that the strength of a post reduces, other elements constant, as the slenderness increases. That the same is true of masonry columns is no doubt true, but the exact place where the effect of slenderness is likely to manifest itself in reduced strength is difficult to determine. The character of the material and workmanship and possible eccentricity in loading while in service are elements difficult of computation.

The Watertown Arsenal Report for 1886 contains a report of a series of tests on fifty-three brick piers, the chief variables

being height and sectional area. An effort, somewhat successful, it is believed, was made to maintain brick, mortar and workmanship constant in quality. From these reports, two typical series have been selected, and of these, a summary is given in the tables below:

Test No.	Height.	Ultimate Strength. Pds per square inch.
851	2′	2,428
852	2′	2,117
853	4′	2,050
854	4′	1,944
855	6′	1,950
856	6′	1,750
857	8′	1,691
858	10′	1,677
859	10′	1,811

Test No.	Height.	Ultimate Strength. Pds. per square inch.
875	2′	2,327
876	2′	2,466
877	4′	1,687
878	4′	1,950
879	6′	1,700
880	6′	1,644
881	8′	1,461
882	8′	1,610
883	10′	1,347

In order to obtain if possible the law connecting strength and slenderness a plot was made on which strength and the ratio of length to diameter were the co-ordinate axes. The various tests were plotted, each test being indicated by a point. A string stretched taut was then employed to obtain the best average straight line for each series. The equations of the straight lines were then obtained and are given below.

Straight line Formulae for the Strength of Matured Brick Piers laid in 1 C: 2 S Mortar:

Eight inch piers, face brick:

$$p = 2400 - 50 \frac{L}{D}$$

Twelve inch piers, common brick:

$$p = 2100 - 75 \frac{L}{D}$$

where p = ultimate crushing strength, pds. per sq. in.
L = length and
D = diameter.

The agreement between the actual values obtained by test and those given by the equations is rather striking. The following table gives the comparison for the first of the two series. It will be observed that the average error is approximately 5% :

FACE BRICK PIERS.

Comparison between Strength as determined by Actual Test, and Strength as computed by Formulae.

Cross Section, 8″ × 8″; mortar, 1C : 2S; age, 21 mos.

Height	Actual Strength. Pds. per square inch.	Computed Strength Pds. per square inch.	Error.
2′	2,428	2,250	−7 %
2′	2,117	2,250	+6 %
4′	2,050	2,100	+2 %
4′	1,944	2,100	+7 %
6′	1,950	1,950	0 %
6′	1,750	1,950	+10 %
8′	1,691	1,800	+6 %
10′	1,677	1,650	—2 %
10′	1,811	1,650	—9 %

An examination of the results for the entire series of fifty-three piers shows that the strength varies with the cross-section as well as with the height, from which it would seem that the ultimate resistance depends in some way upon the volume.

The following straight line formulae by Kidder for the working stresses on brick piers evolved "from numerous tests and from some formulas published by Professor Ira O. Baker and from personal observation" are the results of an effort to recognize the column principle. Kidder suggests that they be applied in cases where the length exceeds six times the least diameter.

Safe loads in pds. per sq. in.

Piers laid in rich lime mortar.

$$p = 110 - 5 \frac{L}{D}$$

Piers laid in 1 to 2 natural cement mortar,

$$p = 140 - 5\tfrac{1}{2} \frac{L}{D}$$

Piers laid in 1 to 3 Portland cement mortar,

$$p = 200 - 6 \frac{L}{D}$$

For a pier 10 ft. high and 1 ft. square, the safe loads in accordance with these formulae would be:

4.3 tons if laid in lime mortar,
6.1 tons if laid in natural cement mortar
and 10.0 tons if laid in Portland cement mortar.

SUMMARY.

1. Bricks of the same material and process of manufacture exhibit considerable variation in physical properties.
2. Results of tests by different experimenters are frequently not comparable owing to difference of method.
3. Where the absorption in bricks is low, the strength is likely to be high, and *vice versa*.
4. The crushing strength is dependent to some extent on the specific gravity of the brick.
5. The strongest piers are those made from the strongest brick in conjunction with the strongest jointing.
6. The use of cement mortar is an economical method of giving increased strength to brick work.
7. The strength of brick masonry improves somewhat with age.
8. The strength of brick piers is a function of their slenderness.

The following is a reprint of an article published in the Transactions of the Engineering Society in 1896, together with some additional matter. The original paper was prepared by Mr. Jos. Keele, B. A. Sc., as a result of experiments conducted in '95-'96 by himself and Professor C. H. C Wright in the Engineering Laboratory of the School of Practical Science. Subsequent experiments, performed from time to time up to the present, have furnished the additional matter, in the collection of which, the assistance of Mr. W. G. Swan, Demonstrator in Strength of Materials, is gratefully acknowledged.

BRICKWORK MASONRY.

Results of Tests made in the Laboratory of the School of Practical Science, Toronto, during the session of 1895-6, by Messrs. Wright and Keele.

JOS. KEELE, B.A.Sc.

BRICKWORK PIERS.

The following tests were made with the object of determining the resistance to crushing offered by piers of ordinary brick, constructed in the same manner and of such materials as those most commonly used in practice in Toronto. These materials will fairly represent those in use throughout the Province of Ontario.

For this purpose a bricklayer and his assistant were engaged to procure from four different brickyards a quantity of each of their grades of bricks, the bricks being taken from the kiln as they came to hand.

The different bricks used were Kingston Road, first, second and third quality; Humber, first and second; Yorkville, first and

second; Carleton, clinker and first, and Don Valley pressed brick, buff and red.

An individual test of each class of brick was made to determine its crushing strength and absorption. The absorption test was made as follows: The dry brick was carefully weighed, then immersed in water, and at the end of twenty minutes the brick was taken out, the surface water dried off, and again weighed. The brick was again immersed until the total time of immersion was thirty minutes, and again weighed.

This was the longest time allowed in water, it having been found in former tests of the same nature that the absorption of water by the brick is practically complete in thirty minutes.

The table of absorption is given below:

Kind of Brick	Weight Dry		Weight after 20 min. in water		Weight after 30 min. in water		Absorption in ounces	Absorption in p.c.
	lbs.	oz.	lbs	oz.	lbs.	oz.	oz.	
Kingston Road, 1st class.....	5	5¾	6	0	6	0	10¼	11.9
" " 2nd "	5	5½	6	2¼	6	2¼	12¾	14.9
" " 3rd "	5	1¾	6	2¼	6	2¼	14¼	17.1
Carlton Clinker...............	5	0¼	5	10	5	10½	10¼	12.7
" " 1st class......	5	0½	5	13½	5	13¾	13¼	16.4
Yorkville, 1st class...........	4	10½	5	11¾	5	11¾	17	22 7
" 2nd "	4	11¾	6	0	6	0	20¼	26.7
Humber, 1st class..............	5	7½	6	2½	6	2½	11	12.6
" 2nd "	5	8	6	6¾	6	4¾	14¾	16.7
Don Valley Pressed, red......	5	13¾	6	6	6	6½	8¾	9.3
" " buff....	5	0	5	15½	5	15¾	15¾	9.7

To ascertain the crushing strength of each quality of brick, two fair and sound samples were selected and bedded between thin layers of Portland cement, thus giving two parallel planes without injury of any kind to the brick.

Ultimate Crushing Strength of Common and Pressed Brick

CLASS OF BRICK	Height	Area Exposed to Crushing in inches	Area sq. ins.	Ultimate Load in pounds	Crushing Strength in lbs. per sq. in.
Kingston Road, 1st class....	2½	8¾ x 4	35	132,400	3,783
" " 2nd "	2½	9 x 4⅛	37	62,000	1,670
	2½	8⅞ x 4⅛	36.6	63,000	1,721
" " 3rd "	2⅝	9 x 4⅛	37	67,600	1,821
	2⅝	8⅞ x 4⅛	36.6	68,000	1,857
Carleton Clinker............	2½	8⅝ x 3⅞	33 4	190,000	5,685
" " 1st class...	2½	8¾ x 4	35	112,000	3,200
Yorkville, 1st class........	2⅝	8⅝ x 4	34.5	160,000	4,637
" 2nd "	2½	8¾ x 4	35	107,000	3,057
	2½	8¾ x 4	35	112,000	3,200
Humber, 1st "	2¼	8⅞ x 4	35.5	43,400	1,222
	2½	8⅝ x 4	34.5	50 000	1,449
" 2nd "	2½	8⅞ x 4¼	36 6	72,000	1,966
	2½	8⅞ x 4¼	36.6	64,000	1,748
Don Valley, red.....	2⅜	8⅜ x 4	34 3	184,000	5,372
" " buff		8½ x 4⅛	35	125,000	3,571

The piers were built by a skilled bricklayer, who also provided the lime mortar, which consisted of 4½ yards of Bloor street coarse sand to ten barrels of lime, this being about the proportion of two parts sand to one part lime. The cement mortar was mixed in the proportion of three parts sand to one part of good Portland cement. While the piers were being built, two cubes of each class of mortar were prepared and set aside for the purpose of ascertaining their resistance to crushing, thus giving a complete record of all the materials used.

Ultimate Crushing Strength of Mortar, 2½ months old

Class	Height in inches	Area Exposed to Crushing in inches	Area sq. ins.	Ultimate Load in pounds	Crushing Strength in lbs. per sq. in.
Lime Mortar, 2 to 1..	5	4⅝ x 4⅞	22.5	1,200	53
" " 2 to 1..	4⅞	4⅝ x 4¾	22	1,700	78
Cement Mortar, 3 to 1	5	5 x 5	25	33,800	1,352

The piers were built and laid aside to harden in the mechanical laboratory of the School of Practical Science, in a temperature which averaged about 60° Fahrenheit, and were prepared for the test as follows: A thin mortar of neat cement was spread on a smooth cast-iron plate, and the pier placed upon the mortar and left until the cement hardened. The bottom bed was then trimmed off flush with the sides, the pier placed on the testing machine, and a layer of neat Portland cement mortar was placed on top, the pier was slid under the head of the machine, and the head was brought to its bearing while the mortar was yet soft.

This method ensured two parallel beds and gave a uniformly distributed stress on the pier. The load was applied slowly and continuously, until complete failure of the pier occurred.

Pier No. 1:

Description—Humber, 1st class, laid in lime mortar, ⅜ in. joints.

Size of pier, 9″ × 9″..........area, 81 square inches
Length, 24 courses ....73 inches
Age ....10 days
Ultimate load ....23,600 pounds
" strength per sq. inch ....291 pounds
" " " foot ....20.9 tons

This pier was built on the testing machine; with lime mortar on top and bottom bed, the head of machine was brought down to a level bearing, and pier allowed to harden in position for ten days.

The pier failed by spreading a little at the head, a wide crack running down the centre to about half the height of the pier.

Pier No. 2:

Description—Kingston Road, 1st class, laid in lime mortar with 3/8″ joints.

Size of pier, 8 7/8″ × 8 7/8″....area, 78.75 square inches
Length, 8 courses ....23 inches
Weight ....114 pounds
Age ....2½ months
Ultimate load .... 44,000 pounds
Crushing strength per square inch........558 pounds
Crushing strength per square foot............40.2 tons

The pier sustained a high load without sign of fracture, but was completely destroyed under the ultimate load.

Pier No. 3:

Description—Kingston Road, 2nd class, laid in lime mortar with 3/8″ joints.

Size of pier 9″ × 9″............area, 81 square inches
Length, 8 courses ....24 inches
Weight ....114 pounds
Age ....2½ months
Crushing strength per square inch } Not determined
Crushing strength per square foot } by experiment.

The bottom bed used in this case was the one-inch board upon which the pier was originally built; the board appeared to be slightly warped, and split under the application of the load, causing a variation in the stress, to which is due the early failure of the pier.

Pier No. 4:

Description—Kingston Road, 3rd class, laid in lime mortar with 3/8″ joints.

Size of pier 9″ × 9″............area, 81 square inches
Length, 8 courses ....24 inches
Weight .... 110 pounds
Age .... 2½ months
Ultimate load .... 24,000 pounds
Crushing strength per square inch ...... 296 pounds
Crushing strength per square foot .... 21.3 tons

Failure occurred by splitting of the bricks in the upper courses, then wide vertical cracks opened throughout the whole length, and under highest load every brick in the pier was shattered.

Pier No. 5:

Description—Humber, 1st class, laid in lime mortar.

Size of pier, 9″ × 9″ .... area, 81 square inches
Length, 8 courses .... 24 inches
Weight .... 122 pounds
Age .... 2½ months
Ultimate load .... 28,000 pounds
Crushing strength per square inch .... 346 pounds
Crushing strength per square foot .... 24.8 tons

The pier held well together until near the ultimate load, then long continuous cracks appeared, with final rupture of the whole pier.

Pier No. 6:

Description—Humber, 2nd class, laid in lime mortar.
Size of pier, 8¾″ × 8¾″ .... area, 76.5 square inches
Length, 8 courses .... 23½ inches
Weight .... 118 pounds
Age .... 2½ months
Ultimate load .... 22,400 pounds
Crushing strength per square inch ...... 293 pounds
Crushing strength per square foot .... 21 tons

All the bricks in the upper portion were completely shattered, the principal failure occurring along one corner of pier.

Pier No. 7:

Description—Carleton Clinker, laid in lime mortar with ⅜″ joints.
Size of pier, 8⅝″ × 8⅜″ .... area, 72 square inches
Length, 8 courses .... 22 inches
Weight .... 114 pounds
Age .... 2½ months
Ultimate load .... 44,000 pounds
Crushing strength per square inch .... 609 pounds
Crushing strength per square foot .... 43.8 tons

The pier failed, with continuous lines of fracture up and down the four sides, only one brick on the lower bed being uninjured after the test.

Pier No. 8:

Description—Carleton, 1st class, laid in mortar with ⅜″ joints.
Size of pier, 8¾″ × 8¾″ ...... area, 76.5 square inches
Length, 8 courses .... 23½ inches
Weight .... 110 pounds
Age .... 2½ months
Ultimate load 41,000 pounds
Crushing strength per square inch .... 535 pounds
Crushing strength per square foot .... 38.5 tons

The pier was completely shattered under the highest load. The mortar crumbled out like sand, and had very little effect in holding any portions of the pier together.

Pier No. 9:

Description—Yorkville, No. 1, white brick, laid in lime mortar with ⅜″ joints.
Size of pier, 8¾″ × 8¾″ ...... area, 76.5 square inches
Length, 5 courses .... 14½ inches
Weight .... 65 pounds
Age .... 2½ months
Ultimate load .... 39,000 pounds

Crushing strength per square inch .... 509 pounds
Crushing strength per square foot .... 36.6 tons

Small cracks appeared as the load was put on. As the highest load was approached portions of the pier spalled off, and finally shattered to fragments under the highest load.

Pier No. 10:

Description—Yorkville white brick No. 2, with pinkish shade, laid in lime mortar with 3/8″ joints.
Size of pier, 8 3/4″ × 8 3/4″ ...... area, 76.5 square inches
Length, 8 courses .... 23 1/2 inches
Weight .... 105 pounds
Age .... 2 1/2 months
Ultimate load .... 30,000 pounds
Crushing strength per square inch ...... 392 pounds
Crushing strength per square foot .... 28.2 tons

Fine cracks appeared early in the test, which increased to long vertical cracks, running the length of the pier, portions of the brick spalled off, and under the highest load given above the pier was totally destroyed.

Pier No. 11:

Description—Don Valley pressed brick, buff color, laid in lime mortar.
Size of pier, 8 5/8″ × 8 5/8″ ...... area, 74.4 square inches
Length, 8 courses .... 21 inches
Weight .... 97 pounds
Age .... 2 1/2 months
Ultimate load .... 51,000 pounds
Crushing strength per square inch .... 686 pounds
Crushing strength per square foot .... 49.4 tons

As the highest load was approached, fine cracks appeared, which were confined to individual bricks, and were not continuous down the length of the pier; the fracture was rather of a crumbling nature.

Pier No. 12:

Description—Don Valley pressed brick, red color, laid in lime mortar.
Size of pier, 8 1/2″ × 8 1/2″ ...... area, 72.25 square inches
Length, 8 courses .... 21 1/2 inches
Weight .... 110 pounds
Age .... 2 1/2 months
Ultimate load .... 88,000 pounds
Crushing strength per square inch ...... 1,218 pounds
Crushing strength per square foot .... 87.7 tons

The failure of this pier was of somewhat the same nature as that of the last, but the brickwork held together better under the ultimate load.

CEMENT PIERS.

Pier No. 13:

Description—Yorkville, 1st class, white color, laid in cement mortar.

Size of pier, 8⅝″ × 8⅝″ . . . . . . area, 74.4 square inches
Length, 8 courses . . . . 24 inches
Weight . . . . 110 pounds
Age . . . . 2½ months
Ultimate load . . . . 79,000 pounds
Ultimate load per square inch . . . . 1,062 pounds
Ultimate load per square foot . . . . 76.5 tons

The pier held together well, and did not show much sign of failure until the highest load was reached; the pier was destroyed in the test, probably owing to the brittle nature of this brick.

Pier No. 14:

Description—Yorkville, 2nd class, color white with pink tint, laid in cement mortar.
Size of pier, 8¾″ × 8¾″ area, 76.5 square inches
Length, 8 courses . . . . 24 inches
Weight . . . . 111 pounds
Age . . . . 2½ months
Ultimate load . . . . 78,000 pounds
Ultimate strength per square inch . . . . . . 1,018 pounds
Ultimate strength per square foot . . . . 73.3 tons

This pier was well built, and shows the value of a cement mortar for laying brickwork, as its binding qualities allow the brick to develop nearly its full strength.

Pier No. 15:

Description—Humber, 2nd class, laid in cement mortar.
Size of pier, 9″ × 9″ . . . . area, 81 square inches
Length, 8 courses . . . . 24 inches
Weight . . . . 124 pounds
Age . . . . 2¼ months
Ultimate load . . . . 91,600 pounds
Ultimate strength per square inch . . . . 1,131 pounds
Ultimate strength per square foot . . . . 81.4 tons

Fine cracks occurred in some of the bricks only under nearly the highest load, but total destruction of the pier took place under the ultimate load, but did not shatter so badly as in the case of those laid in lime mortar.

Pier No. 16:

Description—Kingston Road, 2nd class, laid in cement mortar.
Size of pier, 9″ × 9″ . . . . area, 81 square inches
Length, 8 courses . . . . 23½ inches
Age . . . . 2½ months
Ultimate load . . . . 69,000 pounds
Ultimate strength per square inch . . . . . . 852 pounds
Ultimate strength per square foot . . . . 61.3 tons

This pier held together even under the ultimate load, the failure occurring through actual crushing of some of the upper bricks. After pier was removed from the machine, only small portions of it could be forced away from the mass.

Pier No. 17:

Description—Carleton Clinker, laid in cement mortar.

Size of pier, 8½″ × 8½″ ...... area, 72.25 square inches
Length, 8 courses .... 22¾ inches
Weight .... 115 pounds
Age .... 2½ months
Ultimate load .... 174,000 pounds
Ultimate strength per square inch ...... 2,408 pounds
Ultimate strength per square foot .... 173.4 tons

Fine cracks appeared toward the end of test; these cracks were not continuous down the length of pier, nor did they increase much in width under the highest load.

Pier No. 18:

While working on this pier the friction clutch of the machine gave way, and the tests were discontinued for the present.

Pier No. 1:

Description—The pier in question was tested in December, 1904. It consists of Kingston Road brick, best quality, built in 8 courses and laid in 3:1 cement mortar. The joints were ⅜″ thick.

Size, 8½″ × 8½″ .... area 72.25 square inches
Height .... 2 feet
Age .... 8 years (built in 1896)
Ultimate load .... 184,150 pounds
Crushing strength per square inch ...... 2,550 pounds
Crushing strength per square foot .... 183.5 tons

Pier No. 2:

Description—This pier was tested in January, 1906. It consisted of Carlton 2nd class brick, built in 6 courses, laid in 2:1 lime mortar. The joints were ⅜″ thick.

Size, 8½″ × 8½″ .... area, 72.25 square inches
Height .... 16 inches
Age .... 6 years
Ultimate load .... 75,150 pounds
Crushing strength per square inch ......1,040 pounds
Crushing strength per square foot .... 74.4 tons

Pier No. 3:

Description—This pier was tested in January, 1906. It consisted of Kingston Road 1st class brick, built in 5 courses in 3:1 cement mortar. Joints ⅜″.

Size, 8¾″ × 8¾″ .... area, 76.56 square inches
Height .... 14 inches
Age .... 1 month
Ultimate load .... 117,200 pounds
Crushing strength per square inch ...... 1,530 pounds
Crushing strength per square foot .... 109.4 tons

Pier No. 4:

Description—The pier in question was tested in January, 1906. It consisted of Carleton brick, 2nd class, built in 6 courses and laid in 2:1 lime mortar. The joints were ⅜″ thick.

Size, 8½″ × 8½″ .... area 72.25 square inches
Height .... 1 foot, 5 inches
Age .... 6 years (built in 1900)
Ultimate load .... 75,000 pounds
Crushing strength per square inch ...... 1,040 pounds
Crushing strength per square foot .... 74.9 tons

Pier No. 5:

Description—The pier in question was tested in December, 1907. It consisted of Yorkville brick, 2nd class, built in 5 courses and laid in 2:1 lime mortar. The joints were ⅜″ thick.

Size, 8¾″ × 8¾″ .... area, 76.56 square inches
Height .... 1 foot, 2½ inches
Age .... 2 years
Ultimate load .... 106,000 pounds
Crushing strength per square inch .... 1,382 pounds
Crushing strength per square foot .... 99.5 tons

Pier No. 6:

Description—This pier was tested in January, 1908. It consists of 2nd class Yorkshire brick, built in 5 courses and laid in 3:1 cement mortar. The joints were ⅜″ thick.

Size, 8¾″ × 8¾″ .... area, 76.56 square inches
Height .... 1 foot, 2½ inches
Age .... 2 years
Ultimate load .... 87,000 pounds
Crushing strength per square inch ...... 1,140 pounds
Crushing strength per square foot .... 81.43 tons

Pier No. 7:

Description—The pier in question was tested in January, 1908. It consisted of 5 layers of Humber brick, 2nd class, laid in 2:1 lime mortar. The joints were ⅜″ thick.

Size, 9″ × 9″ .... area, 81 square inches
Height .... 1 foot, 2½ inches
Age .... 2 years, 1 month
Ultimate load .... 43,000 pounds
Crushing strength per square inches ...... 531 pounds
Crushing strength per square foot .... 38.2 tons

Pier No. 8:

Description—This pier was tested in March, 1908. It consisted of Kingston Road 2nd class brick, built in 12 courses, laid in 2:1 lime mortar. The joints were ⅜″ thick.

Size, 8¾″ × 8¾″ .... area, 76.56 square inches
Height .... 2 feet, 10 inches
Age .... 12 years
Ultimate load .... 67,200 pounds
Crushing strength per square inch .... 878 pounds
Crushing strength per square foot .... 62.71 tons

Pier No. 9:

Description—This pier was tested in March, 1908. It consisted of Carlton 1st class brick, built in 6 courses, laid in 3:1 cement mortar. The joints were ⅜″ thick.

Size, 8¾″ × 8¾″ .... area, 76.56 square inches
Height .... 1 foot, 4 inches
Age .... 2 years
Ultimate load .... 74,600 pounds
Crushing strength per square inch ...... 2,281 pounds
Crushing strength per square foot .... 163.94 tons

Pier No. 10:

Description—This pier was tested in March, 1908. It consisted of Don Buff Pressed brick, built in 4 courses, laid in 3:1 cement mortar. The joints were ⅜″ thick.

Size, 8⅝″ × 8⅝″ .... area, 74.4 square inches
Height .... 11 inches
Age .... 2 years
Ultimate load .... 75,000 pounds
Crushing strength per square inch ...... 1,008 pounds
Crushing strength per square foot .... 72.00 tons

Pier No. 11:

Description—This pier was tested in March, 1908. It consisted of Kingston Road 2nd class brick, built in 5 courses, laid in 2:1 lime mortar. The joints were ⅜″ thick.

Size, 8¾″ × 8¾″ .... area, 76.56 square inches
Height .... 14 inches
Age .... 2 years
Ultimate load .... 59,000 pounds
Crushing strength per square inch .... 772 pounds
Crushing strength per square foot .... 55.14 tons

INTERPOLE MOTORS*

F. R. EWART, B.A.Sc.

The use of interpoles, or auxiliary fields of any kind, is mainly to overcome commutation difficulties in machines employed under severe conditions of service. For this reason I shall first describe the process of commutation, then show the effect of induced voltages in the short-circuited coil, proceeding to show how the voltage depends on field form, and how field form is affected by armature reaction. I shall show how the effects of armature reaction may be overcome and under what circumstances an auxiliary field is necessary. And lastly I shall discuss the application of the interpole motor and its many advantages.

Figure A of Figure 1 represents diagrammatically the flow of current in an armature. The coil C carries full current in

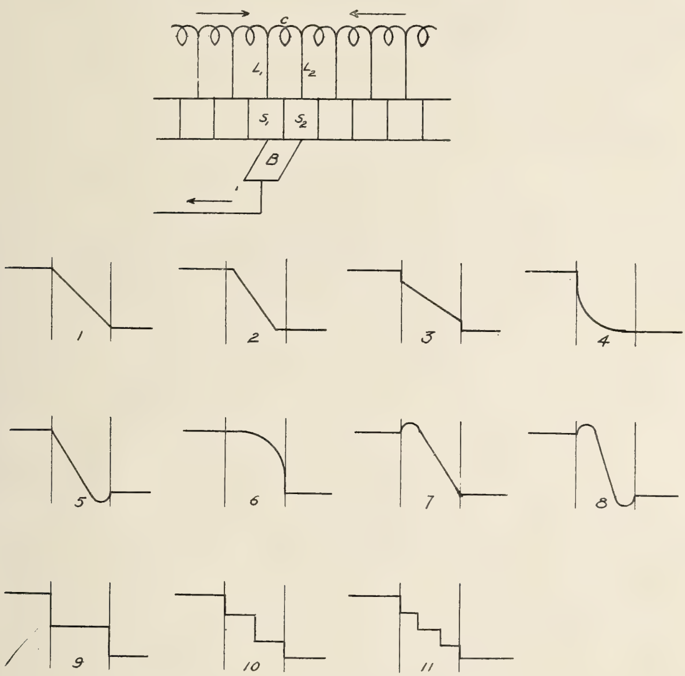


Fig. 1

the right hand direction, and the lead L_1 carries none until the edge of the segment S_1 reaches the heel of the Brush B. As the brush passes over the segment the current is gradually diverted from C through L_1 till half of the brush rests on S_1. The current

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will then pass entirely through L_1, that is the coil is short circuited. As the brush continues its motion the current in L_2 will gradually be shifted to the coil C, until the toe of the brush leaves S_2 and the coil is carrying full current in the left hand sense. That is, the current in the coil is commutated or reversed.

This change may take place in many ways, a few of which are shown in curves 1 to 11, Figure 1. These are curves of current plotted on time interval as base, the distance between the vertical lines representing the time one commutator bar takes to pass a given point. Curve 1 shows the whole time taken in changing the current, while in curve 6 the current hangs on and reverses suddenly, i.e. very little current is diverted by the leading edge of the brush, but is impeded till it has to flow through the trailing edge. This has an effect equivalent to decreasing the width of the brush and increasing the current density. Thus the steepness of the curve indicates the current density at any point. The worst place to have high current density is at the trailing edge of the brush, as this is the point where a segment finally leaves the brush and where a spark once started will be most inclined to be drawn out and maintained. Curve 1 shows ideal commutation, giving uniform and minimum current density in the brush. This condition is most nearly realized by using brushes whose resistance is high in proportion to that of the coil, so that the ratio of currents flowing by L_1 and L_2 depends on the ratio of the surfaces of S_1 and S_2 covered by the brush. This suggests at once one good reason for the use of carbon brushes. If the resistance of the brush is low compared to that of the coil we will get commutation something like curve 9, where the coil is short circuited immediately after the edge of the brush touches its segment.

Armature coils being wound on an iron core and generally deeply imbedded in slots on it, are always highly inductive, so that it is impossible for currents in them to die down rapidly. This self-induction has the effect of producing commutation as in curve 6, causing high density at the trailing edge of the brush, a condition which we have seen to be very harmful.

If we have an active *E. M. F.* in the coil which is counter to the flow of the current and will assist in reversing it, we may get something like curve 4. Evidently the introduction of such an *E. M. F.* might be used to counteract the effect of self-induction, thus effecting a compromise between curves 4 and 6 and securing something near the straight line variation of curve 1.

If, on the other hand, the *E. M. F.* be in the same direction as the current, it will tend to maintain it, and the result may be that the current will be practically undiminished, when the segment leaves the brush and thus force the whole current to arc over from the segment to the brush after they have parted. This would mean sparking of the most vicious kind, a condition which must be remedied at all costs.

For a given speed of rotation, the *E. M. F.* in a coil at any position depends on the density of the magnetic flux at that point. A curve of flux densities on angular positions as a base,

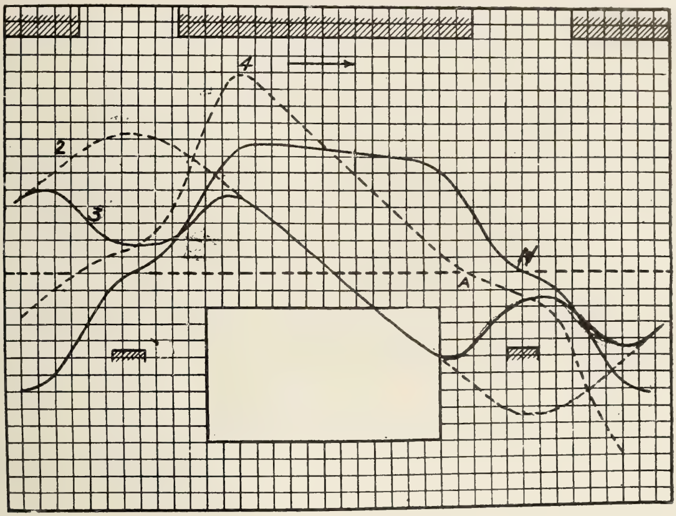

Fig. 2

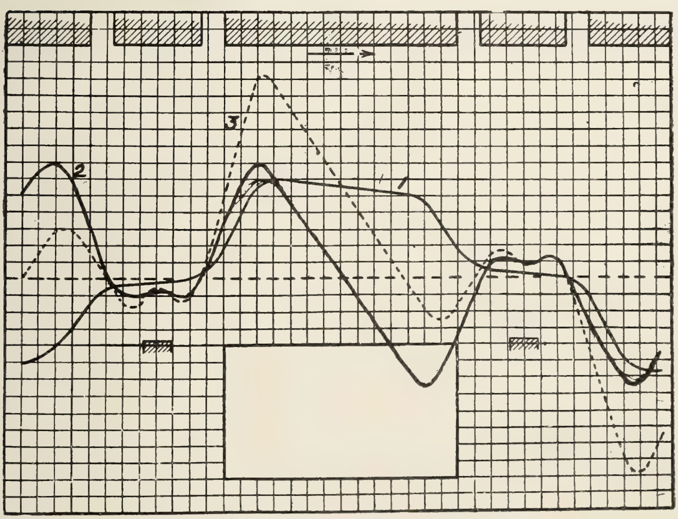

Fig. 3

is called a field form. Curve 1 Fig. 2 is an example of the field form of a shunt motor at no load. The flux is nearly uniform over the face of the pole but rapidly decreases to zero at the

point N in the centre of the interpolar space. The point N is called the neutral point.

Field distribution curves may be determined in three different ways:—

(1) By exploration about the commutator with a voltmeter. This method may be used whether the machine is loaded or not, but in the former case readings in the region of commutation are unsatisfactory, since they are affected by the voltage of self-induction. Thus the main benefit from such measurements is entirely lost.

(2) By means of a fluxmeter and exploring coil. An exploring coil connected to a fluxmeter or galvanometer is inserted in different positions about the field and the kick noted when the coil is withdrawn or the field current cut off. This method can only be employed when the machine is still and can therefore only be used to give the no load curve. The method is therefore of little value in the investigation of field distortions leading to commutation troubles.

(3) The third and best method is to bring out leads to collector rings from two segments at the ends of a coil and take oscillograms of voltage. This method may be used under all conditions of speed, load, etc., and will give an absolutely faithful record of the *E. M. F.* variations in the coil. This will be the same as the field form except when the coil is commutating, where reactance voltage modifies it. But in any case the curve shows the net voltage which is employed to effect commutation, and it is this net voltage upon which commutation mainly depends.

Curve 1 (Fig. 2) is then the no load field form of a shunt motor and is the field produced by the main field alone, being only slightly distorted by the small no load current of the motor. This main field is constant for a definite shunt field excitation and is always in the same position. When the motor is loaded the armature produces a field of its own (Curve 3) which combines with the main field to produce a resultant field as shown in Curve 4.

This armature field varies in magnitude with the armature current, i.e. with the load, and its position is determined by the setting of the brushes. It is evident that an armature has a magnetization due to its own current and that the line of action of this magnetization is determined by the position of the brushes, since that is what determines the points where the current changes its sense. In fact the armature *M. M. F.* is said to be in phase with the brushes, and if commutation were taking place along the neutral axis it would be in quadrature with the *M. M. F.* of the main field. If the machine had a uniform air gap all around the armature, the maximum flux would evidently be at the brushes and zero flux at points half way between. That is we would have an armature flux as shown in Curve 2. The

difference between Curves 2 and 3 is caused by the high magnetic reluctance of the circuit in the interpolar spaces.

Remembering that in the case of the motor, the flow of current is opposite to the induced *E. M. F.*, we see that we must commutate at some point a little before the point of no voltage N is reached, if we are to have a small voltage in the commutating coil acting against the current to overcome the effect of self-induction and obtain sparkless commutation. That is we must shift the brushes back a little and commutate in the "back field" or "fringe." This is in fact the method used to obtain a commutating field on any constant speed shunt motor, and is always easy of accomplishment because the main field is always stronger than the armature field and a fringe (or flux beyond the pole tip) always exists, i.e. the point of no voltage is always outside the pole tip.

But in the case of a variable speed motor, where the high speeds are attained by using a greatly reduced main field, it frequently happens that there is no fringe, i.e. the point of no voltage is under the pole tip. This is the case shown by the full load curve of Fig. 2. In this case it is impossible to get sparkless commutation by shifting the brushes backward because it is impossible for the brushes to catch up to the point A. This is because the armature flux moves with the brushes and when the brushes move under the pole tip, the arm flux at the brush is no longer that shown in Curve 3, but becomes that shown in Curve 2, so that the point A recedes before the brush and cannot be overtaken by it. It must be remembered too, that shifting the brushes backward increases the demagnetizing effect of the armature and decreases the capacity of the motor, and therefore must not be indulged in too freely.

Evidently then under extreme conditions, such as a variable speed motor, where a back field is not available for commutating purposes, a special commutating field must be provided separately. One form of auxiliary field is the winding, which was invented in 1895 by Prof. Ryan and has been called after him. It consists of a winding placed in slots on the pole face and carrying full load current. The direction of these currents is opposite to those of the armature conductors, so that the armature flux is almost exactly counterbalanced at all points. Thus the resultant full load field form differs only slightly from that at no load. This method works excellently, but has one great objection. It is very expensive. It is still used extensively on Series *A. C.* motors, where careful compensation of armature reaction is absolutely essential. But in the case of *D. C.* machines, quite as good results are accomplished much more cheaply by the use of interpoles.

These interpoles are placed in the centre of the interpolar spaces and are wound with series windings, which carry load current in such a sense that their magnetization opposes that of

the armature. They are wound with sufficient turns to not only neutralize the armature flux but to produce a slight extra flux in the opposite sense, to serve as a commutating field. The field distribution curves are shown in Fig. 3. Curve 1 is for no load. Curve 2 shows flux due to armature and interpoles, and Curve 3 shows the resultant field form.

Since the interpoles are excited by the load current, their magnetization bears a constant ratio to that of the armature, and is therefore able to produce a commutating field in the right direction at all loads. It will be noticed that armature reaction is neutralized only in the region of commutation. This is just a narrow spot of unvarying width. "The question then might be asked, whether the same excitation is required on the interpoles for a given load at both high and low speeds. Experiment has proven that if the excitation of the interpoles is correct for high

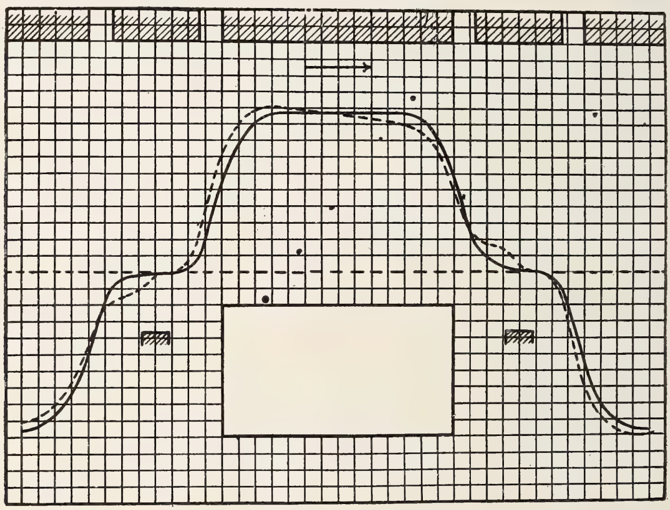

Fig. 4

speeds it is also correct for all lower speeds. For although the same commutating flux is created at a given load irrespective of the speed, yet the *E. M. F.* generated in the short circuited coil is proportional to the speed. Thus a high *E. M. F.* is provided for the very quick reversal of the current at high speed and a much lower *E. M. F.* is provided for the slower reversal at low speed."

Fig. 4 shows the field forms at low speed, i.e. strong main field. The curves are consequently plotted on a much smaller scale than in the other figure, so that the distortion due to armature reaction and interpoles appears relatively small.

The speed regulation of the interpole motor is about the same at all speeds. That is, the rise of speed in *R. P. M.* from

full load to no load is nearly the same for all excitations. The armature $I\ R$ drop at full load is a definite fraction of the terminal voltage irrespective of the excitation and must consequently tend to cause the same percentage decrease of speed from no load to full load. This drop would be greater than in the ordinary shut motor since R includes both armature and auxiliary field winding and is consequently comparatively high. This, however, is compensated for by the fact that the auxiliary field tends to weaken the field at full load, thus causing a tendency for the speed to rise. This fact may be verified by a comparison of the curves in Figs. 2 and 3. These two effects combine to give the machine a speed regulation which is quite as good as that of the average shunt motor of the same rating.

The efficiency for any given load is practically constant. When load is constant, armature current is constant, and then torque varies directly with the armature flux, whereas speed varies inversely as the flux. Since power output varies as the product of torque and speed, it is evident that power output is independent of field flux, i.e. it is constant for a constant value of armature current or power input. Thus the efficiency is constant.

These facts are substantiated fairly well by the curves of Fig. 5, which are derived from a recent test on the interpole motor in the Electrical Laboratory. It will be noticed that the speed regulation seems to show a constant difference in R. P. M. from full load to no load instead of a constant percentage, the variation seeming to be about 60 or 70 R. P. M. for all speeds.

The greatest application of the interpole motor is for machine tool drive. In fact it was for this class of work that the interpole motor was developed, and its advantages for this and other work were brought to the notice of the engineering profession. "The requirements of a variable speed drive demand a motor, in which all the speed variation desired may be obtained in the motor itself without the necessity of either a variable voltage supply or a mechanical speed changing device." Evidently the interpole motor fits these requirements exactly. The elimination of the multi-voltage system effects a great saving in wire, and tends to simplicity in both the generation and application of power. The advantage of a uniform speed gradation, over the wide speed changes effected by any mechanical device, need scarcely be emphasized. The speed ratios employed in practice vary all the way from 2-1 to 6-1.

The motors are generally handled by controllers of the drum type, having contacts for line, armature, and starting resistance on the drum and a field rheostat at the bottom, whose arm is keyed to the main spindle and moves with it. The contacts of the drum are so arranged that the armature polarity may be reversed thus changing the sense of rotation. This also reverses the polarity of the auxiliary field, thus ensuring a com-

mutating field that is always in the proper sense. One common form of controller has 16 forward running positions and 6 backward.

It is common practice to use resistances between points of such values, that the successive speeds are in geometric progression. Thus for 16 running speeds and a 3-1 ratio we have a step to step variation of $\sqrt[15]{3} = 7.6\%$ and for 6-1 ratio $\sqrt[15]{6} =$

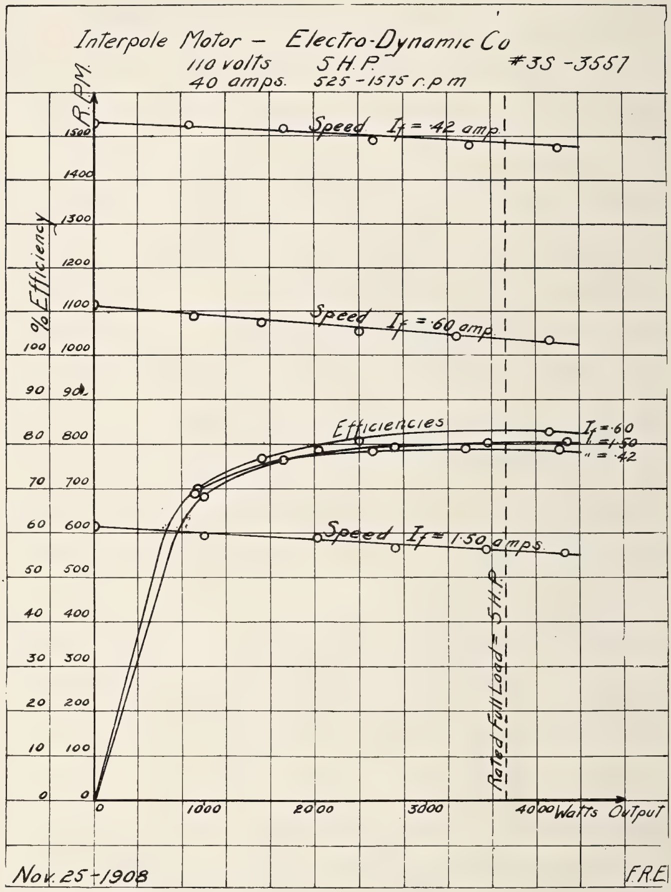

Fig. 5

12.7%. The controller may be mounted in any convenient place and position, and with long lathes is frequently mounted on the tool base so that the workman may always control the speed while standing close to his work.

Several special advantages are claimed for the use of variable speed motors in machine shop work.

(1) Elimination of line shafting.

This not only saves considerable power, but gives greater convenience and flexibility in the placing of machines.

(2) Safety and cleanliness.

Belting is always more or less dangerous and noisy and inclined to throw oil and dust.

(3) Improved and cheapened product.

Machine work is always cleaner cut when turned out at its proper speed. Then, too, the workman can push the work well up to the safe limit and loses no time in gear changing, etc. The Firth-Sterling Steel Co. found that they were able to produce 46% more work from interpole motor driven machines than from corresponding belt driven machines in the same time.

Another important use for interpoles is on railway motors. They are found to have a good effect on commutation, preventing most of the arcing and flashing which so frequently occurs when the motor is starting or is subjected to a heavy momentary overload of any kind. One great advantage of the interpole railway motor rests in the fact that the improvement in commutation permits much higher voltages to be used with safety. E. H. Anderson, designing engineer of the G. E. Co., claims that the commutation is better on an interpole motor at 1200 volts than on a corresponding type without interpoles at 600 volts. He claims that 2500 volts per motor would be quite possible; so that by using two motors in series in a car, and a double track system having the rails as a grounded neutral, 10,000 volts between trolleys might be realized. This would aid materially in the solution of the problem of long interurban lines.

Interpoles have also been frequently applied to generators on account of the advantages gained in regulation and commutation.

The interpole motor has many advantages besides improved commutation, though most of them are the direct result of this improvement.

(1) A cleaner and safer motor on account of the reduction of carbon and copper dust from brushes and commutator.

(2) Increased life of brushes and commutator.

(3) Lower core densities may be used and less iron, hence smaller iron losses; also smaller commutator losses. Thus a higher efficiency.

(4) Heating instead of commutation becomes the determining factor in the output of the machine, so that every pound of material may be worked to its greatest limit.

(5) The permissible reduction of iron raises the proportion of copper to iron, i.e. makes it "a copper machine not an iron machine." Thus a smaller and neater motor, though probably not any cheaper.

(6) Possibility of higher voltages.

(7) Greater facility in design.

(8) Possibility of increasing service capacity of motors by use of forced ventilation.

(9) Gives a perfectly reversible motor.

"It would probably be impossible to construct a commercial 5 *H.P.* shunt motor which could be suddenly reversed at full load without producing any sign of sparking, yet when commutating pole motors are subjected to such treatment the resultant sparking is not noticeable."